**Title:**

# Is there evidence to support the use of the angle of peak torque as a marker of hamstring injury and re-injury risk?

**Authors:**

Ryan G Timmins[1], Anthony J Shield[2], Morgan D Williams[3], David A Opar[1]

[1]School of Exercise Science, Australian Catholic University, Melbourne, Australia

[2]School of Exercise and Nutrition Sciences and Institute of Health and Biomedical Innovation, Queensland University of Technology, Brisbane, Australia

[3]Division of Sport and Science, University of South Wales, Pontypridd, Wales, UK

**Corresponding author:**

**Ryan G. Timmins**

School of Exercise Science, Australian Catholic University, 115 Victoria Parade, Fitzroy, 3065, Melbourne, Victoria, Australia

rgtimm001@myacu.edu.au

Telephone: +61 3 9953 3742

Fax: +61 3 9953 3095

**Running title:**

Angle of peak torque and hamstring injury risk

**Key Points:**

The knee flexor angle of peak torque measure has gained significant attention in the hamstring injury literature as an identifier of injury risk and a return to play measure. This is despite a lack of evidence supporting its use in a predictive capacity. This article presents the limitations associated with this measure as well as alternatives which overcome some of its flaws and assumptions.

**ABSTRACT**

Hamstring strain injuries are the predominant injury in many sports, costing athletes and clubs a significant financial and performance burden. Therefore the ability to identify and intervene with individuals who are considered at a high risk of injury is important. One measure which has grown in popularity as an outcome variable following hamstring intervention/prevention studies and rehabilitation is the angle of peak knee flexor torque. This current opinion article will firstly introduce the measure and the processes behind it. Secondly, this article will summarise how the angle of peak knee flexor torque has been suggested to measure hamstring strain injury risk. Finally various limitations will be presented and outlined as to how they may influence the measure. These include the lack of muscle specificity, the common concentric contraction mode of assessment, reliability of the measure, various neural contributions (such as rate of force development and neuromuscular inhibition) as well as the lack of prospective data showing any predictive value in the measure.

## 1. INTRODUCTION

**Paragraph 1**

Hamstring strain injuries (HSIs) are the most prevalent non-contact injury in cricket [1], soccer [2], rugby union [3] and Australian Football [4]. Over the past two decades in the Australian Football League, the incidence of new HSIs is 6.0 per club per season, resulting in 21.1 player games missed per club per season [4]. Additionally, over the past decade in elite European soccer, the incidence of HSIs has not declined despite a significant scientific effort [5]. As a result the high incidence of HSIs places a significant burden, not only medically but also financially on organisations, with recent calculations placing the average yearly cost of games missed in Australian Football due to HSIs at approximately $A245,842 per club [6]. Due to the impact of this injury, research efforts have been focused on identifying potential risk factors for HSIs [7]. Whilst many of these risk factors, such as previous injury [7, 8], age [9, 8] and deficits in eccentric strength [10-12] have been shown to increase the likelihood of HSIs, many others are supported by limited or circumstantial evidence [13, 14]. One risk factor which has become popular, is the isokinetically derived angle of peak knee flexor torque [14, 15]. Surprisingly it has been used as an outcome measure following hamstring intervention/prevention, rehabilitation and return to play studies, with the inference that this is a marker of re-injury risk, despite limited evidence to support this [16-20]. Considering the small evidence base associated with the measure [13, 14], it has been heavily supported and implemented within the literature [16-26] and professional practice [20, 23-27]. The purpose of this current opinion article is to present the evidence base related to the angle of peak knee flexor torque as a marker of rehabilitation progression, part of the criteria for athlete return to play and a possible predictor of future hamstring injury risk,. This article will then identify the limitations that the measure has and will suggest other possible alternatives.

## 2. IS THE ANGLE OF PEAK TORQUE INDICATIVE OF DAMAGE SUSCEPTIBILITY IN SKELETAL MUSCLE?

**Paragraph 2**

The main rationale for the use of the angle of peak torque to predict HSI risk is based on the concept of the measure being a surrogate for fascicle length, in-series sarcomere strain and is based around the sarcomere popping hypothesis [28]. Morgan (1990) hypothesized that eccentrically induced muscle damage was influenced by the proportion of the range of motion that a muscle is on the descending limb of the force-length relationship. This proportion of the range of motion is thought to be a region of greater sarcomere instability which predisposes to increasing muscle damage. [28-31]. As per this hypothesis, during forceful eccentric contractions, the weakest sarcomeres (those of longer length) display rapid, non-uniform lengthening on the descending limb of the force-length relationship. These weak sarcomeres are uncontrollably elongated to a point where any further lengthening is limited by the passive myofibril structures [28, 32] and it is in this position where the sarcomeres are defined to have 'popped' [28]. If provided sufficient time to recover, these sarcomeres are able to repair and return to a normal length, however when repeated eccentric efforts occur (e.g. during high speed running), these weakened sarcomeres are unable to recover and return to a normal length [32]. These 'popped' sarcomeres cause an increased sarcolemma strain on neighbouring sarcomeres (in-series and in-parallel) and the likelihood of these close-by sarcomeres being 'popped' during subsequent efforts increases [28, 32]. The accumulation of 'popped' sarcomeres, along with increases in the sarcolemma strain, eventually leads to microscopic myofibril damage [28, 32, 33]. As additional microscopic damage amasses with repetitive eccentric contractions, the risk of a macroscopic event occurring, such as a strain injury is suggested to increase [33].

**Paragraph 3**

Longer muscle fascicles, which infer more sarcomeres in-series, are thought to have less sarcomere lengthening per unit of in-series strain [28] when compared to shorter muscle fascicles. As a result this will reduce the proportion of their range of motion which is spent on the descending limb of the force-length relationship, limiting its susceptibility to eccentrically induced muscle damage and potentially reducing the risk of injury [14, 30]. It has been suggested that isokinetic dynamometry can be utilised to detect variations in muscle fascicle length (number of in-series sarcomeres), and therefore potential HSI risk in the knee flexors [14, 15]. The basis of this hypothesis is that possessing longer muscle fascicles (inferred to have more in-series sarcomeres) results in the angle of peak knee flexor torque occurring at longer muscle lengths, where the opposite is thought to occur with shorter muscle fascicles [14]. This current opinion article will examine the evidence relating to the use of the angle of peak torque as a valid measure for the prediction of HSI risk and question its inclusion as a marker of rehabilitation progression and part of the criteria for athlete return to play [16-20].

## 3. TORQUE-JOINT ANGLE RELATIONSHIP

**Paragraph 4**

The assessment of the *in-vivo* force-length relationship is not possible in humans. Therefore surrogate markers have to be used, one of which is the torque-joint angle relationship [15]. The determination of the torque-joint angle relationship is most often done through the use of isokinetic [14, 15] or isometric [34] dynamometry. The torque-joint angle relationship derived from isokinetic dynamometry is influenced by changes in both muscle force and moment arm length throughout a range of motion. This recorded torque can be plotted against joint angle to determine the torque-joint angle relationship [15] and in this case, joint angle is used as the surrogate marker for muscle length. From the isokinetic torque-joint angle relationship, it is possible to determine the optimal joint angle for torque production, which is the joint angle at which peak torque occurs [15]. The isometric torque-joint angle relationship involves maximal isometric contractions at a selection of discreet joint angles throughout the range of motion. The torque recorded at each joint angle can then be utilised to determine the torque-joint angle relationship and the resultant optimal joint angle for torque production [35].

**Paragraph 5**

Differences in muscle architecture have been shown to influence the shape of the torque-joint angle relationship [29, 33], with individuals who have longer vastus lateralis fascicles producing peak knee extension torque at angles corresponding to longer lengths than those with shorter fascicles [36]. By contrast, muscles with shorter fascicle lengths have been shown to spend a greater proportion of the range of motion on the descending limb of the force-length relationship than muscles/muscle groups with longer fascicles in rats [37]. These authors suggested that this would result in an increased susceptibility to damage during eccentric contractions and a greater likelihood of strain injury [33, 37].

**Paragraph 6**

The use of the knee flexor torque-joint angle relationship using maximum voluntary contractions as a measure of HSI risk is potentially flawed as multiple muscles can contribute to the torque produced around a joint as well as having changes in their moment arms with alterations in the knee joint angle[38]. Further to this, the assessment of the knee flexor torque-joint angle relationship is commonly done during slow, concentric contractions and this is also another possible limitation as the majority of HSIs are considered to occur during high speed, eccentric contractions [7, 24, 39]. Additionally the assessment of the knee flexor torque-joint angle relationship through the use of isokinetic dynamometry has displayed poor reproducibility [40]. Furthermore, the transference of this measure to HSI risk is limited as the length of the muscle during the test is not comparable to those seen during high speed running [41]. Finally neural contributions such as the rate of force development and onset of myoelectrical activity can also significantly alter the shape of the torque-joint angle relationship [42, 43].

## 4. MULTIPLE MUSCLES CONTRIBUTE TO TORQUE PRODUCTION DURING KNEE FLEXION

**Paragraph 7**

One aspect the knee flexor torque-joint angle relationship does not take into account is the individual contribution from the different posterior knee muscles to the overall knee flexion torque that is produced. Force (or torque) production during knee flexion is influenced by the three hamstring muscles: biceps femoris (long and short head), semitendinosus and semimembranosus; as well as the gracilis, sartorius and gastrocnemius [38]. Consequently, assessment of the knee flexor torque-joint angle relationship will be influenced by all of the aforementioned muscles.

**Paragraph 8**

A shorter optimal length for peak torque production during concentric knee flexion has been reported in participants with a previously injured hamstring when compared to their contralateral, uninjured limb [14, 16]. It was proposed that this difference in the angle of peak knee flexor torque may increase the susceptibility of the hamstrings to muscle damage and increase the risk of a HSI [13, 14]. This supposition does not consider muscle specificity which is of importance for HSIs, as the biceps femoris long head is the most commonly injured of all the hamstring muscles [44]. As a result, the previously injured biceps femoris long head may possess shorter fascicles and have fewer sarcomeres per centimetre of fascicle length [45]. This will result in it being prone to accumulated muscle damage and consequently macroscopic trauma [28, 32, 45]. However, if the agonist muscles have more sarcomeres per centimetre of fascicle length, the knee flexor angle of peak torque may not present as ‘altered’. In this instance the potentially shorter biceps femoris fascicles, which may increase the likelihood for injury to this muscle specifically, are masked by the architectural characteristics (e.g. fascicle length) of other muscles. However, this cannot be distinguished from the torque-joint angle measurement. Additionally, selectively stimulating biceps femoris long head at discreet joint angles throughout the range of motion may allow the determination of its contribution and its propensity for muscle damage. However this method has never been attempted in the literature. Therefore it may be better suited to utilise imaging techniques such as two-dimensional ultrasound or magnetic resonance imaging to allow for a more muscle and site specific assessment of muscle architecture [45].

## 5. CONTRACTION MODE OF ASSESSMENT

**Paragraph 9**

The knee flexor torque-joint angle relationship is often determined during slow (normally 60°/s) concentric contractions on an isokinetic dynamometer, although it can be determined at most velocities, as well as during eccentric and isometric efforts [13-15]. It has been suggested that contractions at these slower, concentric velocities are more reliable than eccentric efforts or faster concentric speeds and minimises the effects of the rate of force/torque development [13-15]. With reference to the use of slow concentric speeds, the majority of HSIs often occur during the terminal swing phase of high speed running, with a small amount occurring during stretching and kicking actions [7, 24, 39, 46]. During the terminal swing phase of high speed running, forceful eccentric contraction of the hamstrings are required to decelerate the flexing hip and extending knee [7, 47]. Therefore eccentric contraction appears to be integral to the aetiology of running based HSIs [7]. As such the application of angle of peak knee flexor torque data derived from concentric contractions may have limited transference to eccentric function. It could be argued that utilising an eccentrically derived angle of peak torque might have greater transference to the injury mechanism. However during voluntary eccentric actions, it is very difficult to obtain maximal motor unit recruitment which creates issues of validity and reliability with an eccentric assessment [48, 49]. Additionally, it is not possible to draw conclusions as to whether the knee flexor angle of peak torque measure may be more/less useful for other injury mechanisms such as stretch and kicking induced injuries.

## 6. RELIABILITY OF THE ANGLE OF PEAK TORQUE

**Paragraph 10**

The test-retest reliability of a measure is important for any meaningful implications to be made [50]. One reasoning behind the use of slow concentric contractions to determine the torque-joint angle relationship is because of the increased reliability of the measure under these conditions [15]. However, in healthy participants, the test-retest reliability of the knee flexor angle of peak torque using concentric contractions at 60°/s is low (ICC dominant leg:

0.519, non-dominant: 0.079) [51]. This level of test-retest reliability is supported in elite volleyball players, with an ICC of 0.67 during concentric knee flexion contractions at 180°/s [52]. A review by Gleeson and Mercer (1996) indicated that the assessment of the angle of peak torque "demonstrates the greatest measurement error and weakest reliability" when compared to other measures of isokinetic strength (e.g. peak torque and peak torque ratios such as hamstring:quadriceps) [40]. Poor reproducibility of isokinetic measures is increased when only assessed on a single visit, without a separate familiarisation session employed [40]. The reliability of the measure will also be influenced by how the angle of peak torque is calculated. The different methods used to calculate the angle of peak torque include a fitted model utilising torque and joint angle data across the range of motion [14, 15, 34], normalising values to the peak torque recorded [53] and through the use of isometric dynamometry [35]. At this point there is no consensus as to which approach is best, or has greater reliability.

## 7. MUSCLE LENGTH DURING PEAK TORQUE PRODUCTION

**Paragraph 11**

During the assessment of the knee flexor torque-joint angle relationship, uninjured knee flexors create peak torque at approximately 26° to 32° (where 0° = full knee extension) [14, 15, 17, 54]. This measurement is collected with the hip flexed to 85-90$^{o}$. Therefore angle of peak knee flexor torque during isokinetic dynamometry typically occurs with the hip and knee flexed to 85° and 30° respectively. With these joint angles it can be estimated that the length of the biceps femoris long head is 34% greater in a seated dynamometry test than in upright stance [55]. In comparison, during the terminal swing phase of high speed running, the biceps femoris only lengthens 9-12% compared to upright stance [41, 56]. These estimates suggest that the change in muscle length of the biceps femoris long head during the assessment of the torque-joint angle relationship is up to three times greater than that noted during the terminal swing phase of running [57] and this may limit the applicability of the angle of peak torque measure to HSI risk prediction and as part of the criteria for athlete return to play.

## 8. NEURAL CONTRIBUTIONS TO THE TORQUE-JOINT ANGLE RELATIONSHIP

**Paragraph 12**

Variations in the architectural characteristics of a muscle have been suggested to be the cause of alterations in the torque-joint angle relationship [14, 32]. However, other factors, mainly neural, may also influence the shape of the torque-joint angle relationship [42]. One factor is the magnitude of early onset of muscle activity, a combination of both recruitment and rate coding, commonly measured by electromyography [42, 43]. At the commencement of a contraction, the greater the increase in activity, the faster the increase in torque [42]. A faster rate of force/torque development will lead to a shift in the optimum angle in a direction of longer muscle lengths [42]. The extent of this shift can be altered by the level of participant motivation and learning effects. As a result, changes in the optimum angle can occur without any alterations in the mechanical properties of the muscle being tested. Additionally fibre type distribution, the frequency of action potentials, , stiffness of the muscle-tendon complex and neural drive of the muscles being tested may also impact the optimum length [58, 59]. Another factor which may alter the shape of the torque-joint angle relationship is the differential levels of inhibition noted throughout a range of motion [38, 61]. Participants with a unilateral history of biceps femoris long head strain injury exhibit significant inhibition in the previously injured muscle, which is accentuated at long muscle lengths [38, 61]. Therefore a combination of all of these factors, without any changes in muscle structure, will influence the torque-joint angle relationship.

**Paragraph 13**

Additionally, individuals with a unilateral HSI history have a significantly lower rate of force development and myoelectrical activity in the biceps femoris long head during anticipated eccentric contractions in the previously injured knee flexors [62, 38, 61]. These individuals also display a lower level of early onset muscular activity in the previously injured biceps femoris than the contralateral uninjured biceps femoris [62]. These differences can account for variations in the torque-joint angle relationship between limbs, with the previously injured limb having a peak torque occurring at shorter lengths, independent of any architectural differences. Therefore, it is possible that individuals with hamstring architecture designed towards creating force at long muscle lengths (e.g. more sarcomeres per centimetre of fascicle length) could record an angle of peak torque at relatively short muscle lengths if their ability to quickly recruit the knee flexors is poor. This is particularly so during concentric contractions, where knee flexion commences from a position close to full knee extension. Previous research has largely failed to consider these neural contributions [14, 15].

## 9. PROSPECTIVE USE OF THE TORQUE-JOINT ANGLE RELATIONSHIP

**Paragraph 14**

Robust, prospective studies are required to determine injury risk factors [63]. Retrospective studies are not able to distinguish if the differences that are found were present before the injury occurred, or were altered as a result of the incident [63].

**Paragraph 15**

There is only one prospective study which has investigated the relationship between the knee flexor angle of peak torque and future HSI risk [64]. This investigation in elite and sub-elite sprinters from Hong Kong found no association between the knee flexor angle of peak torque and HSI rates during a competitive season [64]. Retrospective studies have found a greater angle of peak knee flexor torque (shorter length) in a previously injured limb when compared to the contralateral uninjured side [14, 16]. However, as it is not possible to know if these differences existed prior to the initial insult occurring or were altered due to the injury, the inferences from these data is limited.

## 10. ALTERNATIVE METHODS TO ASSESS HAMSTRING STRAIN INJURY RISK

**Paragraph 16**

In light of the aforementioned limitations with the angle of peak knee flexor torque determined during concentric contraction, the following section will propose alternative approaches

### 10.1 Assessing muscle architecture

**Paragraph 17**

As the torque-joint angle relationship is suggested as a surrogate marker of muscle architecture, it would appear prudent to consider a measure of hamstring muscle architecture as an alternative approach. Of all the methods available for the *in-vivo* assessment of muscle architecture [29], two-dimensional ultrasound is the most cost-effective and time-efficient and is reported to be a valid [65] and reliable [45, 66] measure of hamstring muscle architecture. The benefit of this technique is that it allows for the assessment of architectural characteristics of individual muscles. Given the propensity of HSIs to occur in the biceps femoris, the measurement of fascicle length and pennation angle in this muscle might be a more specific measure, compared to a global knee flexor measure such as the knee flexor angle of peak torque. Recently it has been shown that limbs with a previous biceps femoris long head strain injury display shorter biceps femoris long head fascicles compared to the contralateral uninjured muscle [45]. Further, unpublished work from our laboratory has shown that soccer players who display shorter biceps femoris long head fascicles at the beginning of pre-season training are up to 4-times more likely to sustain a future HSI compared to those with longer fascicles. Whether measures of biceps femoris fascicle length are useful because it gives a muscle specific insight into the force-length relationship of biceps femoris remains unknown. Regardless, early indications suggest that fascicle length measures have the ability to differentiate cohorts with a previous injury to biceps femoris long head and, importantly, those at risk of future HSI, which the knee flexor angle of peak torque measures has thus far failed to do.

### 10.2 Isometric assessment of the angle of peak torque with electrical stimulation

**Paragraph 18**

The addition of movement to an assessment of muscle length-tension (torque-joint angle relationship) properties during a voluntary contraction adds a number of other variables that have the potential to adversely affecting the validity and reliability of optimum angle (as mentioned in the preceding sections). Optimum lengths, in many of the seminal animal studies on this topic, were typically constructed using isometric contractions [67, 68]. An isometric approach has the potential to overcome many of the limitations raised in this article. This requires a greater amount of time to complete compared to dynamic contractions, as multiple isometric contractions are required to construct a torque-joint angle relationship, and they must be timed and ordered to minimise effects of fatigue.

### 10.3 Serial monitoring of the torque-joint angle relationship

**Paragraph 19**

Although this approach might be limited by the poor reliability of the measure, it is possible that the serial measures of the angle of peak knee flexor torque could be considered as a monitoring tool to indicate hamstring fatigue and or damage. It may be that serial monitoring improves the reproducibility of the angle of peak torque measure through a learning effect; however the many limitations within the measurement technique would still restrict the application of this measure.

## 11. CONCLUSIONS

**Paragraph 20**

The prevention of HSIs in elite sporting environments is of vital importance; however the various methods for assessing injury risk must be considered in light of the scientific literature. This article critically analysed the use of the torque-joint angle relationship for predicting an athlete's risk of suffering a HSI and part of the criteria for athlete return to play following injury. It then presented various alternatives which overcome some, but not all of these limitations. Due to these limitations the potential of the angle of peak torque measure and its efficacy in injury prevention and rehabilitation is yet to be seen. Future work in developing a predictive model for HSIs should consider the various factors which may influence the risk of an injury occurring. Of these, the torque-joint angle relationship may play some role in determining risk; however the use of the measure alone in a predictive sense is insufficient.

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